Mechanized Harvesting of Napier Grass and Other Hawaiian Forage Crops

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Bulletin 102
UNIVERSITY OF HAWAII AGRICULTURAL EXPERIMENT STATION
FEBRUARY 1950

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ACKNOWLEDGMENTS

I wish to acknowledge the valuable assistance of Professor Rene Guillou, Head, Department of Agricultural Engineering, University of Hawaii Experiment Station, and John C. Ripperton, Head, Department of Agronomy, University of Hawaii Experiment Station. Mr. William R. Ford and Mr. Robert A. Fraser, Waialae Ranch; Mr. Alan Faye, Waimea Sugar Company; Mr. Tom Liggett, Manager, Puunene Dairy; and Mr. Toshi Ansai, Manager, Wailuku Sugar Company Dairy, arranged for the use of fields and the loan of equipment. The principal machine shop work, welding, and assembly of the various machines were performed by Mr. William Kirschbaum and Mr. Richard Kam of the University of Hawaii Agricultural Engineering Department.

Mechanized
HARVESTING OF NAPIER GRASS AND OTHER HAWAIIAN FORAGE CROPS

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INTRODUCTION

One of the problems of the Hawaii dairy industry is the high cost of feed, and a controlling factor in the cost of island green forage is hand labor. Green forage is cut, chopped, and fed fresh daily. No green feed is stored since Hawaiian agriculture is geared to year-round production. The corn binder has been introduced for use with koa haole (ekoa, *Leucaena glauca*) but does not operate successfully with Napier grass. Forage crops are harvested successfully in dairy regions of the Mainland with far less labor than in Hawaii. It is thought that substituting machinery for hand labor will substantially reduce man-hours per ton of forage harvested and consequently reduce feed costs. Whereas mowing and chopping Napier grass for chopped green forage takes 4 man-hours per ton with an efficient crew, mechanical harvesting with field forage harvester choppers should reduce the mowing and chopping operations to 0.3 man-hour per ton.

This project was set up primarily to develop laborsaving machinery for harvesting Napier grass. It was proposed to attack the problem by developing existing field forage harvesting equipment to meet the high yields and widely stooled crops, to operate over ditches, and to operate with relatively short rows and lack of headlands.

REVIEW OF THE LITERATURE

This review briefly embodies various labor requirements and costs of mainland forage harvesting operations, which differ from Hawaiian forage harvesting methods. However, in both cases dairy forage crops must be mowed and chopped before feeding. Therefore, the significance of a comparison between the two regions comes from a man-hour and cost per-ton basis for the various harvesting operations.

Lower forage production costs in Hawaii might be reflected in a drop in the price of fresh milk and in lower sales of canned and reconstituted milk. Through the introduction of alfalfa and other crops, present Hawaiian harvesting practices may become modified. It should be noted that some dairies graze their crops rather than investing in machinery for harvesting and chopping green forage.

Mowing and chopping are common to the Mainland and to Hawaii. Dow (*4*), Lamborn (*9*), Keeper (*7*), and Collins (*2*) report on labor requirements for mowing as follows:

Total Labor per Acre
Tractor Mower 7-Foot Bar

LOCALITY	HOURS PER ACRE
Maine	0.62
Vermont	0.45
New York	0.60
Pennsylvania	0.50

The total cost for mowing, including labor, power, and machinery, varied from 71 cents to 94 cents per acre.

Webster and Lamborn (*18*, *8*), reporting on the investment per cow and investment per acre in hay harvesting equipment, state that the cost per cow for the conventional loaders, buckrakes, and auto buckrakes varied from $10.65 to $17.13; for the buckrake and blower combination the cost was $22.74; and for the field forage harvester the cost was $31.56. The investment per acre varied from $5.10 to $10.54, when conventional haying equipment was used, to $26.16 with the field forage harvester.

Lamborn (*10*, *11*) found that the total cost of harvesting hay on a per-ton basis varied from $3.20 to $4.89. The total man-hours per ton varied from 2.0 with the field harvester chopper to 5.0 for hand-pitched methods. The loader and wagon combination showed 3.5 man-hours per ton.

Duffee (*5*) in 1943 harvested corn and grass for silage under actual farm conditions with a 40-inch cut field forage harvester including corn attachment, tractor, and wagons. With a five-man crew the total labor required to harvest the crop and fill the silo was 0.72 man-hour per ton for corn silage and 0.88 man-hour per ton for grass silage.

Stippler (*17*) gives a comparison of three different methods of making silage. The figures for the first two methods involve loading, transportation to the silo, and chopping at the silo with a stationary chopper. The third method, concerning the field forage harvester-chopper operation, includes windrow pick-up chopping, transportation to silo, and silo filling. Stippler found that 2.0 man-hours per ton were required for hand-loading methods, 1.6 man-hours per ton for mechanical loading, and 1.5 man-hours per ton for forage harvesters. The average size crew was 8.1 men for hand loading, 7.6 men for mechanical loading, and 4 men for field harvester choppers.

NAPIER GRASS AS A FORAGE CROP (*6*, *12*, *16*, and *19*)

Napier grass (*Pennisetum purpureum*) or elephant grass was introduced into Hawaii in 1915 and is now used extensively as a green dairy roughage. It outranks all other dairy roughages grown in Hawaii in yields per acre of green forage and of dry matter, and it is very palatable and nutritious when cut in the early stages of growth. The grass grows to a height of 12 to 14 feet and yields up to 40 to 60 tons per acre per cutting, with an average closer to 20 to 30 tons per acre. There are normally three to four cuttings per year. The crop tillers extensively and ratoons freely. Dairy cows consume 60 to 70 pounds per day or 1 ton per cow per month.

The crop is planted in rows 3½ to 4 feet apart. Portions of the stalk or root, as planting material, are placed either on the ridge or in the furrow bottom. Furrow irrigation is used, but the University of Hawaii Dairy is

FIGURE 1. Harvesting Napier grass with hand sickle.

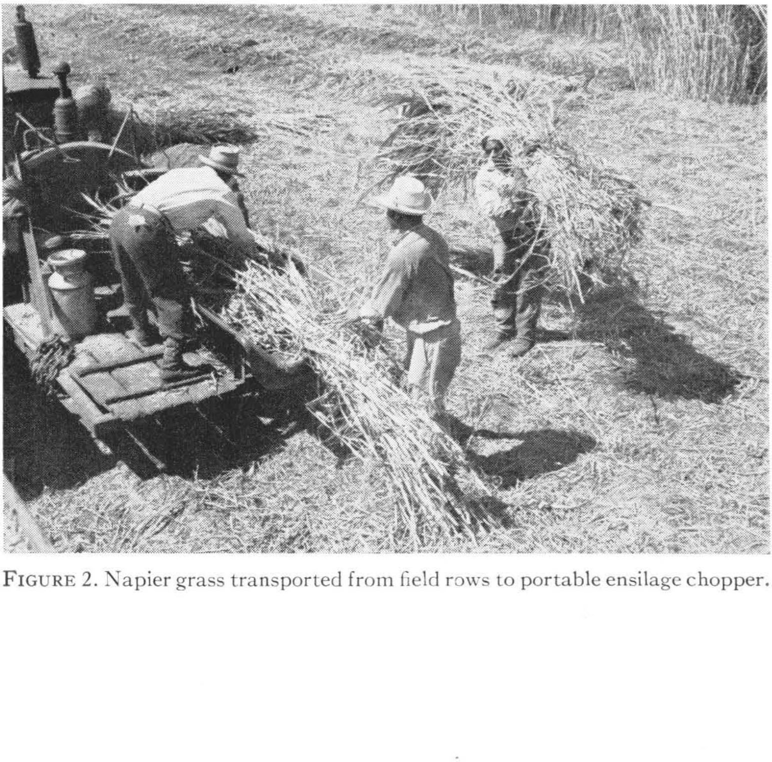


FIGURE 2. Napier grass transported from field rows to portable ensilage chopper.

FIGURE 3. McCormick-Deering Farmall A Tractor with 5-foot mower attachment used in mowing operations in some Napier fields.

now experimenting with overhead irrigation on lands with shallow soil and uneven terrain. Normally, no waste water ditches are provided. In the wet regions no supplemental water is used and yields are somewhat lower than in the irrigated areas.

Where lack of headlands, rough terrain, rocks, deep irrigation furrows, ditches, and cramped small fields are not a factor in harvesting, most Napier grass fields are laid out for hand labor field operation. Napier grass is not usually planted on the best lands, which are devoted to other crops believed to be more profitable. (Many Napier fields are not flat and of even terrain.) With continuous cropping and irrigation the fields become very ridged and rough. Most fields are plowed and replanted every 10 years. Some fields can be easily adapted to harvesting machinery, but on the whole wheel equipment suffers severe treatment when harvesting under present conditions. The lack of headlands presents a problem since machinery cannot maneuver at the end of the rows without knocking down standing material. A continuous around-the-field arrangement of cutting could be worked out in the larger fields, but it would not be entirely satisfactory because of the manner in which the harvesters would have to operate to open a field. However, cutting in one direction with square corners has proved satisfactory, and hand labor has been employed to cut the first 8 feet of land circumscribing the field. In other cases the grass was run down by the tractor and later harvested by hand. The need for harvesting in the rain makes field operations with wheel equipment difficult except when equipped with special spades or chains.

PRESENT FIELD HARVESTING METHODS

One generally used method is to cut the standing crop with a 3- to 5-foot tractor mower. Before another swath is cut, the grass is piled in 40- to 60-pound bundles and laid in rows in the field. One local dairy uses two crews, one for cutting and the other for chopping. The cutting crew consist of a tractor driver and four men to mow, gather, and bundle the grass. A chopper crew of five men with a tractor-drawn Diesel-powered ensilage chopper mounted on a four-wheel trailer moves about the field. Four men pick up the bundles and feed the ensilage chopper while the fifth man acts as operator. The grass is blown into a special four-wheel farm wagon which holds 1.75 tons of green chopped forage. This dairy ranch mixes molasses with the grass as it issues from the blower spout.

Another method is to haul the whole stalks by wagon to the ensilage chopper located near the feed barn. Here the material is fed into the electric power-driven chopper directly from the wagon.

LABOR REQUIREMENTS

1. Dairy No. 1*—Observations on a single day

Round trip to field	0.92 man-hour per ton
Mow	0.01
Pile	0.97
Load	0.92
Chop	0.60
Level in bin	0.07
Load chopped material	0.43
Round trip to pens	0.82
Fill feed racks	0.76
Total	5.51 man-hours per ton

* From notes taken January 10, 1947, by Professor Rene Guillou, Head, Department of Agricultural Engineering, University of Hawaii Experiment Station.

Dairy No. 1—Totals for the year 1946–47*

Yield tons 565.45 or 75.5 tons per acre for an area of 7.84 acres.

OPERATIONS	MAN-HOURS	MAN-HOURS PER TON	MAN-HOURS PER ACRE
Hand cutting†	82	0.15	10.5
Mowing	320	0.57	40.8
Loading and hauling	1,151	2.03	146.8
Total harvesting	1,553	2.73	198.1

* From a letter by Professor Henke, Head, Department of Animal Husbandry, University of Hawaii Experiment Station, on March 8, 1948.

† Hand cutting in addition to mowing is necessary to open fields and pick up standing grass not cut by the mower.

2. Dairy No. 2—Field data taken over a 5-day period
   Mowing: Tractor 3-foot bar
   Five-man crew—5 hours daily or 25 man-hours per day
   Chopping:
   Five-man crew—3 hours daily or 15 man-hours per day

Total	40 man-hours per day
Average forage per day..........	10.5 tons
Average man-hours per ton.......	3.8

3. Dairy No. 3—Estimated averages
   This dairy reports 8 to 9 man-hours per ton for cutting, chopping, and placement in feed racks.

COSTS

There are at present two general methods of harvesting Napier grass for green forage. Let us compare these two methods on a cost per-ton basis including overhead and operating costs. This study includes the costs and equipment necessary to mow and chop the forage into feed and the labor involved in operating the machinery and piling the grass into bundles in the field but does not include the equipment or labor for hauling and feeding the chopped grass.

METHOD I—CHOPPING IN FIELD WITH PORTABLE CHOPPER

1. Cut by mower.
2. Pile by hand.
3. Carry whole stalk to portable field ensilage chopper.
4. Chop directly into wagons.

METHOD II—CHOPPING AT BARN WITH STATIONARY CHOPPER

1. Cut by mower.
2. Pile by hand.
3. Load whole stalks on wagon.
4. Haul grass to barn.
5. Unload whole stalks to ensilage chopper.
6. Chop either into overhead storage bin or directly into wagon.

Method II calls for equipment to transport the whole grass to the barn for chopping. This study assumes that the costs of bringing chopped feed or whole stalks to the barn are identical; therefore they have not been included in the total costs under Method II.

Under both methods the mowing and piling operations are assumed to be identical. Any saving between the two practices should come from a more efficient use of labor in preparing grass for feed once it has been mowed and piled. Fewer man-hours per ton are expended in loading grass onto the conveyor pan of a portable ensilage chopper in the field than in loading a wagon with whole stalks. Another saving is achieved by deleting the unloading operation at the barn. It is estimated that ½ man-hour per ton is needed to unload a wagon of whole stalks to an ensilage chopper at the barn.

However, chopping in the field necessitates mounting an ensilage chopper and power unit on a wagon. This involves considerably more initial expense than installing an electric motor and ensilage chopper at the barn. Table 1 gives the equipment inventory and life of equipment for both methods.

TABLE 1. Present dairy harvesting methods equipment inventory.
Method I—Field chopping

	NEW COST HONOLULU, 1949	LIFE	
		Hours	Tons
Wheel tractor, 16-drawbar horsepower	$1,535	9,000	18,000
5-foot mower attachment for tractor	300	2,000	18,000
Trailer mounted ensilage chopper consisting of the following units:			
Ensilage chopper, throat capacity 106 square inches	755	4,000	18,000
Power unit, 30 horsepower, gasoline	925	9,000	40,500
Trailer for power unit and chopper plus V-belt drive	1,600	9,000	40,500
Total	$5,115		
Method II—Barn chopping			
Wheel tractor, 16-drawbar horsepower	$1,535	9,000	18,000
5-foot mower attachment for tractor	300	2,000	18,000
Electric motor,* 20 horsepower	370	10,000	45,000
Ensilage chopper, throat capacity 106 square inches plus V-belt drive and installation	855	4,000	18,000
Total	$3,060		

* Includes base and starting box.

Table 2 shows the overhead and operating costs in dollars per ton for field chopping and barn chopping in dairy units of various sizes. Overhead costs are broken down into depreciation and interest; operating costs are broken down into fuel, oil, and repairs. Field chopping, which has the more costly equipage inventory, shows higher overhead charges. The operating charges for barn chopping are lower than field chopping in the 6,000- to 2,400-ton-per-year bracket, but higher in the 1,200- and 600-ton-per-year bracket. The main factor responsible for higher barn chopping operating costs for smaller dairies is the increase in electrical energy charge per ton. Electrical energy is sold in blocks and the greater the use the lower the cost per kilowatt hour.

In dairies of all sizes barn chopping produced lower overhead and operating costs per ton, not including the additional labor requirements. Additional labor is required to unload the whole stalks to the ensilage chopper at the barn, which increases the total man-hours per ton from 3.5 for field chopping to 4.0 for barn chopping. With labor at 80 cents per hour, an additional 40 cents per ton must be added to the cost of barn

TABLE 2. Present dairy harvesting practices —overhead and operating costs, dollars per ton.

Method I—Field chopping

Tons per Year	6,000	4,800	3,600	2,400	1,200	600
Overhead costs						
Depreciation						
Tractor, mower, chopper, trailer, and power unit	0.21	0.21	0.21	0.24	0.36	0.72
Interest	.02	.03	.04	.05	.11	.21
Operating costs						
Fuel, oil, and repairs	.36	.36	.36	.36	.36	.36
Labor @ 3.5 man-hours per ton	2.80	2.80	2.80	2.80	2.80	2.80
Total	3.39	3.40	3.41	3.45	3.68	4.09

Method II—Barn chopping

Tons per Year	6,000	4,800	3,600	2,400	1,200	600
Overhead costs						
Depreciation						
Tractor, mower, chopper, and electric motor	0.17	0.17	0.17	0.18	0.22	0.44
Interest	.01	.02	.02	.03	.06	.13
Operating costs						
Fuel, electric energy, oil, and repairs	.34	.36	.37	.38	.41	.61
Labor @ 4 man-hours per ton	3.20	3.20	3.20	3.20	3.20	3.20
Total	3.72	3.75	3.76	3.79	3.89	4.38

chopping. With this addition, chopping at the barn shows the higher cost per ton for dairies of all sizes.

Explanation of the various measurements used to construct table 2 follows:

FIELD CHOPPING

I. *Overhead Costs*

A. *Depreciation*

Tractor is depreciated in 9,000 hours or 18,000 tons except for the 1,200- and 600-ton dairies, where the life has been set at 13 years.

Mower is depreciated in 2,000 hours or 18,000 tons except for the 2,400-, 1,200-, and 600-ton dairies, where the life is 5 years.

Chopping rates average 4.5 tons per hour. The life of the engine and trailer is set at 9,000 hours or 40,500 tons. The life of the ensilage chopper is set at 4,000 hours. Engine and trailer depreciate in 13 years when chopping 2,400 tons or less per year. The depreciation of this equipment in 13 years amounts to $195 per year. Chopper is depreciated in 13 years when chopping 1,200 tons and less per year and this depreciation amounts to $58 yearly.

B. *Interest*

Interest is calculated at 5 percent of the average value.

II. *Operating Costs*

A. *Fuel and Oil, Tractor*

Tractor, mowing: Fuel costs are based on 2.5 tons per hour. Gasoline consumption is taken at 1 gallon per hour under varying loads. The tractor idles when not mowing. Cost for fuel is 9.2 cents per ton. Oil is figured at 3 cents per hour or 1.2 cents per ton.

B. *Fuel and Oil, Engine*

The chopping engine fuel consumption is based on an average 20-horsepower output during the chopping period. Fuel consumption was taken from the engine characteristics curve and was 2.32 gallons per hour. Gasoline is figured at 23 cents per gallon, fuel charges at 53.4 cents per hour, and chopper engine oil at 3 cents per hour.

C. *Repairs*

Tractor repairs are based on 8 cents per hour, or 3.2 cents per ton.

Mower repairs are figured on 4 percent of new cost per 100 hours of use, or 4.8 cents per ton at 2.5 tons per hour.

The chopper engine life before overhaul is figured at 1,800 hours. Repair charges are figured at 6 cents per hour.

The trailer repairs are based on a charge of 2 percent of the new value per 1,000 hours of use, or 3.2 cents per hour.

The ensilage chopper repairs are based on 2 percent of the new value per 700 tons of use, or 2.2 cents per ton.

D. *Labor*

Labor is figured at 3.5 man-hours per ton at 80 cents per hour.

Barn Chopping

I. *Overhead Costs*

A. *Depreciation*

For depreciation on the tractor and mower, see overhead costs under field chopping.

The electric motor is depreciated over 10,000 hours or 20 years, and the ensilage chopper is depreciated over 4,000 hours or 18,000 tons of use, except when chopping 1,200 tons or less per year, in which case depreciation is taken over a 13-year period and amounts to $65.77 per year. Chopping rates are figured at 4.5 tons per hour. It was estimated that ½ man-hour is required to unload a wagon containing whole stalks of grass into the stationary ensilage chopper.

B. *Interest*

Interest is figured at 5 percent of the average value of the equipment.

II. *Operating Costs*

A. Fuel and oil charges for the tractors are given under field chopping. Electrical energy charges are based on a chopping rate of 4.5 tons per hour at an average 20-horsepower output over the chopping period. Schedule D, General Power Service Revised Sheet No. 63, Hawaiian Electric Company, was used as a basis for calculating the energy charges.

B. *Repairs*

Repairs for the tractor and mower are shown under field chopping.

Electric motor repairs are based on 0.5 percent of new value per 700 tons of chopped grass, or 0.3 cent per ton.

Ensilage chopper repairs are based on 2 percent of new value per 700 tons of chopped grass, or 2.4 cents per ton.

TRAIL-TYPE FORAGE CHOPPERS

EXPERIMENTAL METHODS AND PROCEDURE

A review of all likely makes and models of corn ensilage harvesters was made. A No. 2 McCormick-Deering corn field forage chopper was purchased principally because it was the only known forage harvester in stock in Hawaii. This machine is a trail type without auxiliary power, is equipped with a spiral knife cutter, and has a 64-square-inch throat area. Preliminary field trials were held January 2, 1948, using a 24-drawbar horsepower wheel tractor (McCormick-Deering Farmall H) in first gear and wide-open throttle.[1] Results indicated an inadequate power supply plus choking and slugging of the grass in the hopper and spiral feed rolls. Choking also occurred in the feeder trough below the rotary cutting knives, and when the mass of Napier exceeded the capacity of the machine and stopped its operation. Slugging resulted from improper feeding of Napier to the chopping unit.

Under field operating conditions the stalk butts remained in the butt pan while the stalk tops accumulated in the hopper. Sometime during this accumulation period the whole mass as a slug would start into the chopping unit, choke, and stop the machine. A 40-drawbar horsepower track-type tractor (International T-9) was substituted for the Farmall H with the same results. Identical conditions were encountered when operating under a split-row condition which was used to reduce the grass intake to the machine. Under split-row conditions the machine was operated to take only one-half the full width of material between its gatherer shoes. The left wheel ran down uncut material, which would necessitate some modification.

To study the machine more carefully, a drawing-board analysis was proposed. (See figure 4.) Physical dimensions, sprocket speeds, and chain

[1] With power-take-off operated harvesters the power-take-off speed depends on engine speed. Power comes from the transmission. Hence, slow field speeds with the tractor engine running slow mean slow operating speed and little power to the harvester.

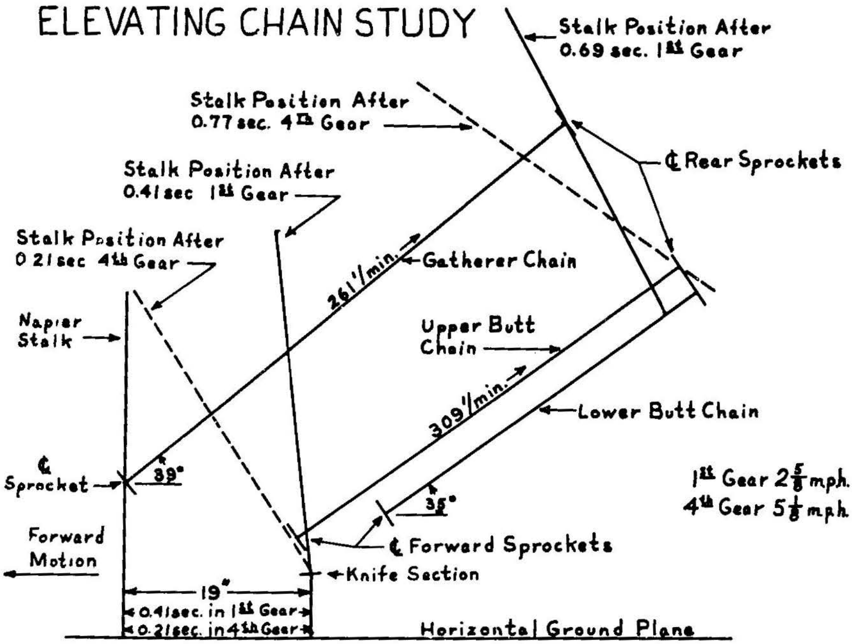


FIGURE 4. Elevating chain study. No. 2 McCormick-Deering field forage chopper.

speeds were shown on the drawing-board, and the path of a single rigid stalk of Napier grass was plotted through the machine, assuming the harvester at two different ground speeds. Very definite conclusions were obtained. Three elevator chains are used on this harvester: the top or gatherer chains and the lower two, or the upper and lower butt, chains. A differential speed exists between the gatherer chains and the upper and lower butt chains. The gatherer chain engages the stalk 19 inches horizontally before it is cut by the sickle and engaged by the butt chain. This procedure takes 0.41 second in first gear and 0.21 second in fourth gear. Here is the critical point in the analysis. In 0.41 second under forward travel in first gear the stalk has progress 21 out of the total 57 inches along the gatherer chain before the butts are cut and engaged by the butt chains. The stalk at this position tilts forward about 6°. The remainder of the stalk travel takes 0.69 second before the gatherer chain lugs discharge the stalk to the spiral feed rolls. However, in 0.69 second the butts still lack 3.75 inches of travel before they are clear of the butt pan and released by the butt chains to the lower feed rolls. Therefore, in spite of the existing differential speed of the chains and the tractor's being in first gear, the top is released ahead of the butts, and the resulting action by the spiral feed rolls is to force the butts back down the butt pan, thus choking the hopper and spiral feed rolls with oncoming material.

However, a packer finger, on the right side of the machine opposite the upper butt chain sprocket, places the butts in position to feed into the lower feed rolls. The eccentric action of this packer finger produces a forward reach of 3½ inches down the butt pan from the center line of the sprocket, and engages the stalk material that is held between the throat spring and butt chains. The packer finger shoves the stalk butts about 6 inches past the center line of the sprocket. In performing this operation the packer finger produces a withdrawing motion from the butt pan just after it passes the center line of the sprocket, and the stalk butts are engaged by the finger only about 32.5 percent of the time. Part of the packer finger cycle will rectify condition 1, where the butts need to be placed in a favorable position in relation to the feed rolls, but during the remainder of the cycle 13½ out of 20 inches of chain travel takes place without help from the packer.

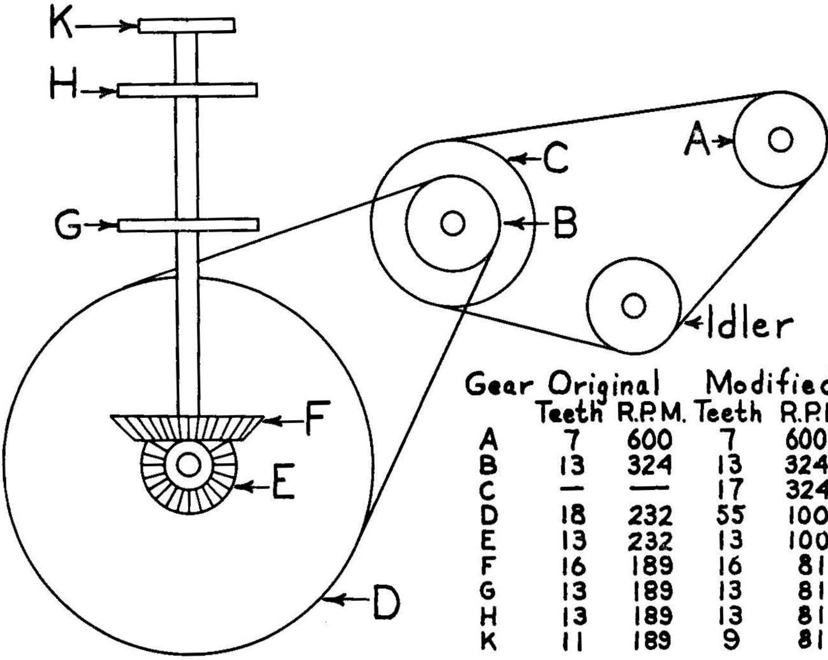
During the forward travel of the machine, pulled by a tractor in fourth gear, the gatherer chain elevates the stalk only 11 inches along the chain before the butts are cut and engaged by the butt chains. This provides a greater initial tilt and the butts are released to the lower feed rolls before the gatherer chain has released the tops. Hence, the butts are placed at the proper entry angle to the feed rolls and the stalk is fed to the chopping unit without difficulty.

This analysis was proved by field trials in fourth gear, and choke-free operation resulted. But with the present rough fields it is almost a physical impossibility to drive the equipment in fourth gear.

In order to duplicate a high-gear relationship when the tractor is in first gear the 18-tooth countershaft sprocket that drove all the elevating chains was replaced by a 45-tooth sprocket. (See figure 5.) A new, longer countershaft was fabricated to accommodate a different position of this gear and still keep the slip clutch in operation. The front fluted feed roll shaft was also lengthened to accommodate two separate sprockets. Thus modified the machine was field-tested in first gear and operated choke-free. The McCormick-Deering Farmall H seemed to have sufficient power for full machine capacity in first gear to cut 15-ton grass. Results showed a chopping rate of 3,140 pounds in 14 minutes actual cutting time or 233 pounds per minute and 0.15 man-hour per ton.

After field trials on the University Farm under light yield conditions, the harvester was further tested at Waialae Dairy Ranch, Oahu. Field trials in 25-ton grass were conducted under both full-cut and split-row conditions on March 17, 18, and 19. Under full-cut conditions the machine was operated to take a full width of material between the gatherer shoes (23 inches). Under split-row conditions the machine was operated to take only one-half the full width of material between its gatherer shoes. The grass had been wind-blown during growth and the tops had profuse secondary growth. Some of the stalks were leaning up to 45° against the travel of the harvester. Since the elevating chains could not rectify this radical departure from a vertical position, considerable trouble was experienced with choking in the feed rolls and inability of the Farmall H to supply adequate power. A full cut was not possible because of the heavy stand. A 33-drawbar horsepower wheel tractor (McCormick-Deering Farmall M) was substituted for the Farmall H, but the increased power only twisted apart two universal joints. A slip clutch was installed on the power-take-off to prevent further universal joint breakage. The

GATHERER AND BUTT CHAIN DRIVE SYSTEM



Gear	Original Teeth	Original R.P.M.	Modified Teeth	Modified R.P.M.
A	7	600	7	600
B	13	324	13	324
C	—	—	17	324
D	18	232	55	100
E	13	232	13	100
F	16	189	16	81
G	13	189	13	81
H	13	189	13	81
K	11	189	9	81

FIGURE 5. Original and final modified sprocket arrangement. No. 2 McCormick-Deering field forage chopper.

11-tooth gatherer chain (upper chain) driver sprocket was replaced by a 9-tooth sprocket, which gave a greater differential speed between the chains and provided a more decided slope to the stalk as it entered the feed rolls. (See figure 5.) However, slugging was still present as the change in speed was not adequate and the stalk butts still were not placed in the proper entry angle, leading to an accumulation of material in the feed chopper. Periodically, the accumulated material would start through the feed rolls and chopper unit in a slug which overloaded the machine and immediately stalled the tractor.

To test this conclusion the same field was cut at right angles (across the furrows) to the direction in which the stalks were leaning. Cutting in this direction produced an even feed into the machine and did not cause choking or slugging. A full cut could be made in 25-ton Napier, and the Farmall H had enough power if the feed was uniform but had very little reserve power in sections of heavy growth. These trials indicated that the machine should be modified as follows:

1. Install not less than a 20-horsepower auxiliary power unit to keep the harvester at full operating speed and independent of the tractor ground speed.
2. Slow the forward ground speed of the harvester to 1 mile per hour or less.

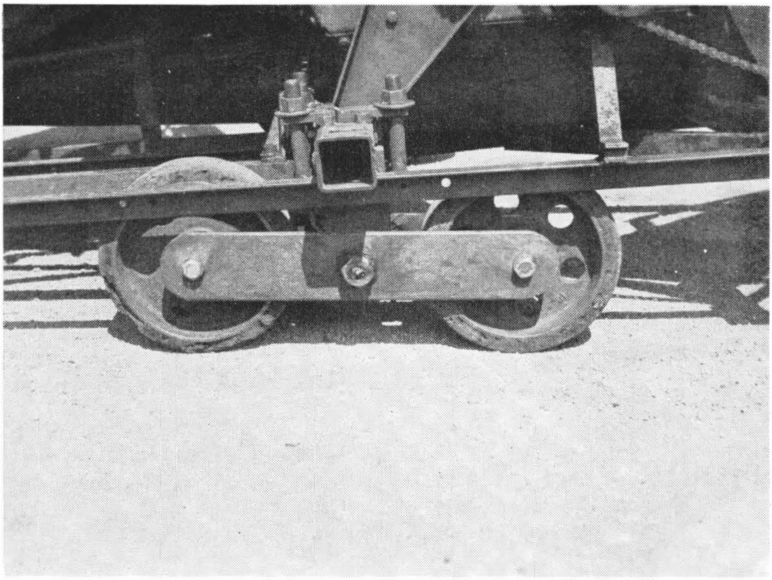


FIGURE 6. Two-wheel truck fabricated for No. 2 McCormick-Deering field forage chopper. Used in lieu of left wheel which ran down uncut Napier grass.

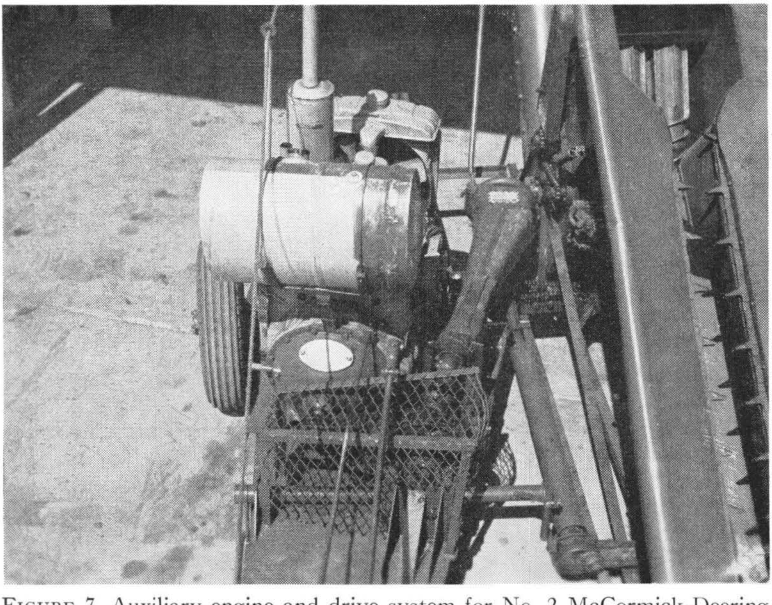


FIGURE 7. Auxiliary engine and drive system for No. 2 McCormick-Deering field forage chopper. An auxiliary engine provides an independent power source which maintains the harvester at operating speed regardless of the tractor ground speed.

Inclusion of all modifications produced the following trail-type harvester:

1. The left wheel was replaced by a two-wheel truck which was fabricated and bolted to the left side of the axle under and between the left outer and inner angles. (See figure 6.)
2. The gatherer chain speed was reduced from 261 to 93 feet per minute and the butt chain speed was reduced from 309 to 133 feet per minute.
3. A 20-horsepower auxiliary engine was installed to keep the harvester at full operating speed and independent of the tractor speed.
4. A blower attachment replaced the paddle-type elevator.

Figure 7 shows the 22-horsepower International U-2 power unit and clutch assembly mounted on a channel iron base.

A sprocket and triple-strand roller chain drive reduced the engine speed to approximately 540 revolutions per minute, power-take-off speed. One sprocket was mounted directly on the clutch stub shaft and the other on the countershaft. The countershaft was supported at either end by self-aligning bearings and was connected to the drive head on the harvester by a set of universal joints and a telescoping torque tube.

Field tests at both the University and Waialae Ranch showed that auxiliary power kept the harvester at an efficient operating level and that ground speed could be varied according to growth conditions. The elevating chain mechanism operated satisfactorily in a range of ground speeds while in first gear.

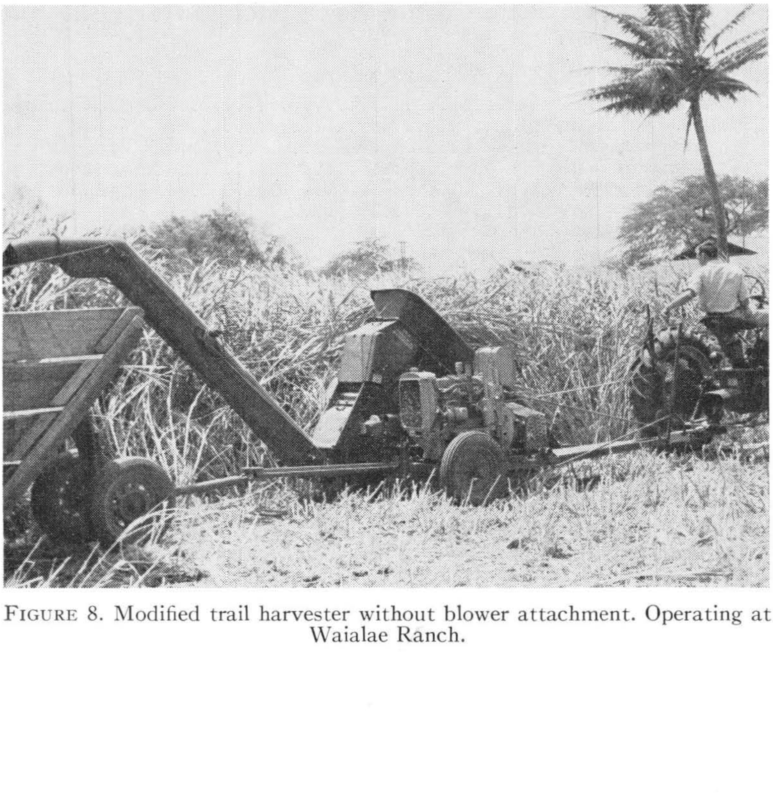


FIGURE 8. Modified trail harvester without blower attachment. Operating at Waialae Ranch.

The machine, as finally modified, operated with a 20-horsepower auxiliary engine at 1 mile per hour (depending upon the wind and field conditions) at full cut (23 inches), in 15- to 25-ton grass. Extended field trials produced harvesting rates above 3½ tons per hour. A slow ground speed enabled the machine to operate in rough fields without noticeable damage and limited the material intake of the machine to within its capacity. (See figure 8.)

FIELD COST STUDIES

The harvester was taken to Waialae Dairy Ranch, Oahu, on April 26 to study field operating costs and harvesting rates. The regular forage wagons were pulled behind the harvester. These wagons were weighed empty and full on portable drive-on scales. Time of starting and stopping was taken by a stop watch. Fuel tanks were full at the start of operations and the weight of fuel required to refill the tanks at the end of the test was recorded. The oil consumption was estimated from previous experience with the equipment. One man operated both the tractor and harvester, stopping occasionally to distribute the load in the trailer. An improved discharge deflector may have reduced the number of these stops.

Stoppage occurred three times during the test, and was not included in the total operating schedule. However, maneuvering, changing wagons, and distributing the load were included as part of the operation. Once the harvester was caught in a mud hole. The second stop was due to the snapping of the tilting rod and crank. The third casualty, which parted the wagon hitch, was caused primarily by operating over deep field irrigation furrows which subjected the wagon hitch to severe shock loads, especially when filled.

The results of this test were as follows:

Operating time	3 hours 20 minutes
Number of wagon loads	9
Maximum load—gross	5,200 pounds
Maximum load—net	3,500 pounds
Average load—net	2,724 pounds
Total tonnage harvested	12.2
Gasoline consumption—tractor	4 gallons
Gasoline consumption—harvester	5¼ gallons
Gasoline consumption—total	9¼ gallons
Gasoline cost @ 23¢ per gallon	$2.13
Oil—cost estimated at 3⅓ hours at 6¢ per hour	$0.20
Total fuel and oil	$2.33
Rate of harvesting and chopping	3.7 tons per hour
Man-hours per ton	0.27
Labor cost @ 80¢ per hour	$0.22 per ton
Fuel and oil cost per ton	$0.19 per ton

ECONOMICS

Tables 3 and 4 have been prepared to show the equipment inventory and overhead and operating costs for harvesting Napier grass by tractor and trail-type field forage harvesters.

Table 3 shows a wheel tractor, forage harvester, and 20-horsepower air-cooled auxiliary engine. The engine mount has been included in the price of the engine even though it would normally be fabricated locally.

TABLE 3. Trail-type field forage choppers—equipment inventory.

	COST HONOLULU, 1949	LIFE
Wheel tractor, 24-drawbar horsepower	$1,900	9,000 hours
Field forage harvester chopper, throat capacity 64 square inches	1,500	6,000 tons
Power unit, 20-horsepower air-cooled engine and engine mount	1,175	6,000 tons
Total	$4,575	

TABLE 4. Trail-type field forage choppers—overhead and operating costs, dollars per ton.

Tons per Year	6,000	4,800	3,600	2,400	1,200	600
Overhead costs						
Depreciation						
Tractor	0.06	0.06	0.06	0.06	0.12	0.24
Harvester and power unit	.45	.45	.45	.45	.45	.45
Interest	.02	.02	.03	.05	.10	.19
Operating costs						
Fuel and oil	.19	.19	.19	.19	.19	.19
Repairs	.12	.12	.12	.12	.12	.12
Labor	.22	.22	.22	.22	.22	.22
Total	1.06	1.06	1.07	1.09	1.20	1.41

Mule cleats for the wheel tractor, priced at $132 per set, may be necessary to keep the outfit operating under wet field conditions.

Table 4 shows a breakdown of overhead and operating costs on a cost-per-ton basis.

It is assumed that the tractor will be used only for harvesting. To be strictly fair some percentage of the interest and depreciation costs should be charged to other work about the dairy.

The harvesting cost varies from $1.11 per ton for the 6,000-ton unit to $1.46 for the 600-ton unit. The 35-cent difference is due to the variable overhead costs.

Various measures used in this section follow:

I. *Overhead Costs*

A. *Depreciation*

Harvesting rates average 3.6 tons per hour over smooth ground. The life of the tractor is set at 9,000 hours or 32,400 tons.

It is assumed that the power unit and harvester will have a life of 10 years for the 600-ton-per-year dairy, and the tractor will have a life of 13 years for the 2,400-, 1,200-, and 600-ton-per-year dairies.

B. *Interest*

Interest is based on an average value at 5 percent.

II. *Operating Costs*

A. *Fuel and Oil*

Field data show this cost to be $0.19 per ton.

B. *Repairs*

Tractor repairs are based on 12 cents per hour, or $0.033 per ton. Harvester repairs are based on a charge of 3 percent of the new value per 700 tons of usage, or $0.065 per ton. Auxiliary power unit repairs are figured on 6 cents per hour, or $0.17 per ton.

C. *Labor*

Field data show a labor requirement of 0.27 man-hour per ton. With labor at 80 cents per hour the cost per ton is $0.22.

FOX FIELD FORAGE HARVESTER

To increase the general knowledge of the adaptability of various makes of forage harvesters, the Waimea Dairy on Kauai loaned the Experiment Station a new Fox forage harvester equipped with auxiliary power. The chopping unit has a conventional four 20-inch knife cylinder chopper and a throat capacity of 111 square inches. This particular harvester is equipped with two detachable heads—one for corn and one for low-growing crops. The latter head is provided with interchangeable windrow pick-up and mower attachments. The corn head was used in Napier grass. However, considerable time was spent operating the mower bar unit in panicum grass with excellent results and without modification.

Field operation on Kauai showed the same inadequacies found with the No. 2 McCormick-Deering. When pulled with a 33-drawbar horsepower Caterpillar track-type tractor (D4) at wide-open throttle in third and fourth gear satisfactory operation was obtained, but in first and second gear the ground speeds were too low to establish the proper entry angle of the stalk butt to the chopping unit.

Preliminary field trials at Waialae Ranch at 2.6 miles per hour in 26-ton Napier gave very good results. The harvester was operating with the wind,[2] and therefore a lower speed was used. At no time was the harvester overloaded. The machine chopped 3,350 pounds of grass in 7 minutes and 5 seconds, a rate of 475 pounds per minute. At 50-percent field efficiency a ton of forage could be harvested in 8.4 minutes. However, the field speed was too high for continuous field operations and the right wheel ran down the uncut material. (See figure 9.)

An attempt was made to rotate the harvester with respect to the wheels and axles by placing wedges between the brackets which secure the wheels and axles to the main frame. A 7° rotation was considered ample to place the gathering points in such a position that the right wheel

[2] The wind blows the grass away from a perpendicular position with respect to the ground. If the grass is tilted away from the harvester a slower ground speed is used and if tilted toward the harvester a higher ground speed is used.

FIGURE 9. Fox harvester before modification. Note how right wheel flattened the grass.

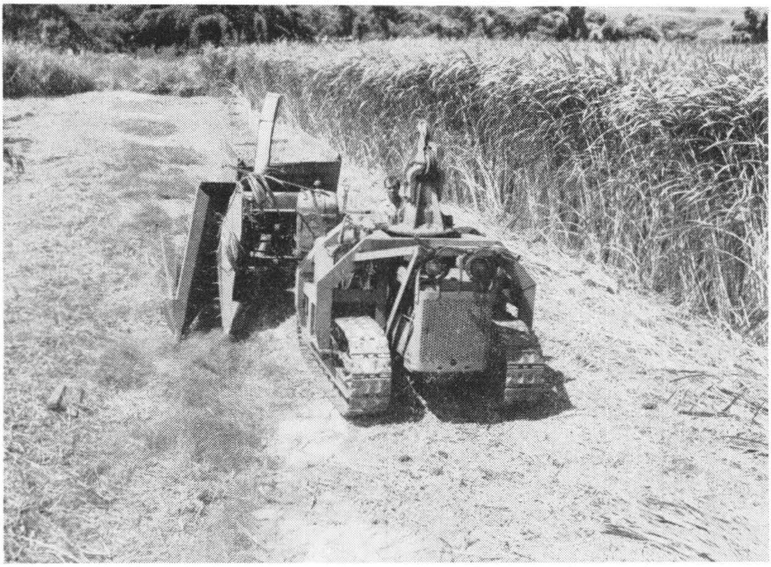


FIGURE 10. Fox harvester operating at Waialae Ranch. Harvester has been rotated 7° with respect to the wheels and axle in order to prevent the right wheel from running down uncut grass. Note condition of field after cutting two rows.

would run over stubble instead of uncut grass. This trial was not successful, because turning the machine reduced the effective opening between the gathering points and much grass was pushed over and not cut. (See figure 10.)

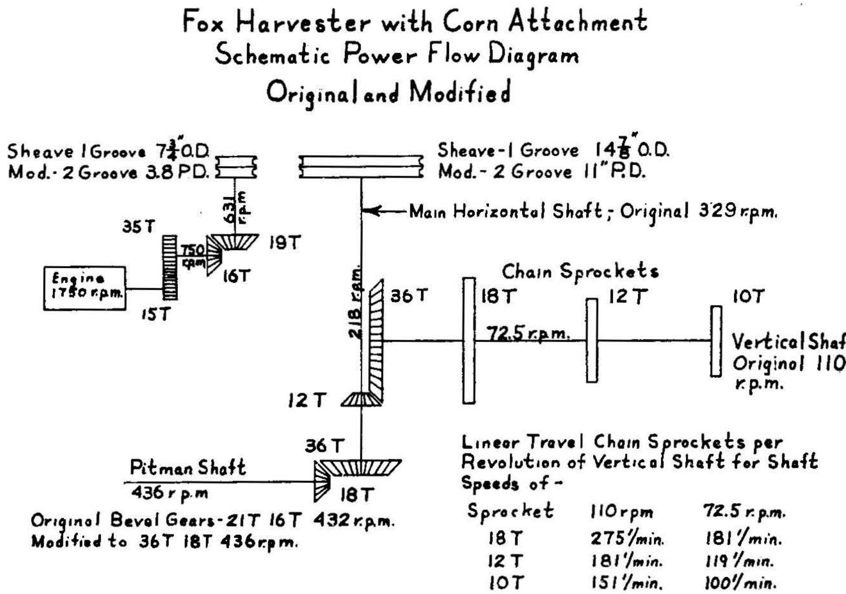


FIGURE 11. Fox harvester with corn attachment: schematic power flow diagram, original and modified.

To eliminate these two difficulties the harvester underwent two modifications. (1) The elevator chain drive was slowed, as was the pitman, which receives power from the chain drive. But by replacing the sickle drive bevel gears with a 2:1 ratio this condition was corrected. (See figure 11.) (2) A three-wheel truck was placed under the right axle and was used in lieu of the regular right wheel. This truck was fabricated from three 16-inch pneumatic General Wheel assemblies which were mounted on a common axle and secured to the harvester with brackets. The original

TABLE 5. Material cost for modification of Fox harvester.

1	Double groove pulley 3.8 inches, pitch diameter	$ 4.80
1	Double groove pulley 11 inches, pitch diameter	14.30
4	V-Belts B112—⅝ inch	13.20
1	Bevel gear, 18 teeth	18.35
1	Bevel gear, 36 teeth	26.25
3	General Wheel assembly	69.63
12′	No. 45 chain	3.72
4′	No. 62 chain	1.60
	Total	$151.85

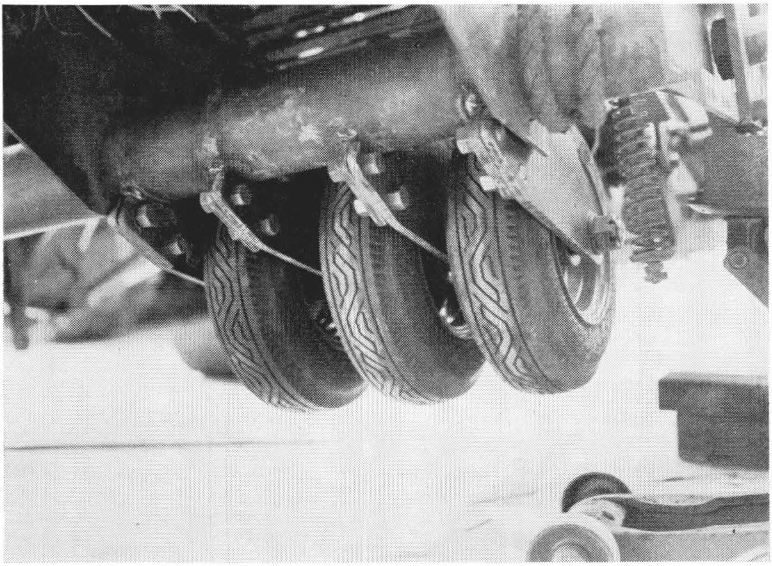


FIGURE 12. Three-wheel truck fabricated for Fox harvester and replacing the right wheel.

right wheel was removed. Table 5 gives a bill of material for this modification. In a series of successful field trials the stubble left in the field was about 6 inches long when the harvester operated on fairly smooth ground. Waimea Dairy on Kauai reports that this modification was not successful under their sandy soil conditions, since the three-wheel truck sank into the soft ground.

DISCUSSION

At present few dairies in Hawaii could use trail-type equipment, as it is adapted to relatively smooth land and large fields. Cultivated land becomes rough from use of furrows for irrigation. Shallow furrows will provide satisfactory irrigation practices. Small, irregularly shaped fields reduce the field efficiency and increase harvesting costs because of longer engine-hours and man-hours per ton of chopped feed. Headlands are not essential but do provide the necessary ground for maneuvering at the end of each row. However, headlands are normally planted because of high land values and as a means of weed control.

Overhead, border, and furrow irrigation can be used, and each method has its own advantages. Waialae Ranch on Oahu now has one field under border irrigation.

Auxiliary power mounted on the harvester is preferred. Power-take-off driven equipment is dependent on the tractor engine speed. If the tractor speed is reduced the power-take-off speed is slowed and the power input to the harvester drops. Normally the tractor is slowed because of high grass intake to the machine at just the moment when the harvester needs most power.

Cutting grass across the planted line gives a more even feed to the machine and keeps the harvester operating under a capacity load, which reduces machine hours in the field. Cutting along the line does not provide an even feed. Some rows have bare sections while others have sections of very dense growth. In old fields where there is profuse stooling, one row cannot be cut at one pass and part of a row is left for the next trip around. In newly planted fields one row is easily taken by the machine, but dense growth may overload the chopper unit.

The harvesting costs per ton of chopped feed compare favorably with those in the hay harvesting sections of the Mainland. Murphy (*13*) (1947) found in New York State that the total cost per ton for harvesting grass silage from the field to the silo, including labor, power, and machinery, was $1.84. Total costs under actual field trials (table 4) varied from $1.06 to $1.41 for harvesting and chopping. Under Pennsylvania (*7*) conditions (1945) the machinery costs alone amounted to $1.12 per ton.

The life in tons of this type of forage harvester is not known, although with relatively high repair costs 6,000 tons is believed to be the limit.

The Fox harvester with auxiliary power is a large capacity machine. Field tests show a 2:4¾ ratio capacity between the McCormick-Deering and the Fox.

Trail equipment could be eliminated if a bin and harvester unit could be mounted on a tractor as a single machinery unit. A tractor-mounted machine has many advantages over trail-type equipment except for the initial cost. In order to build a satisfactory self-propelled machine an investment from $11,000 to $12,000 is required. This also means that a tractor is tied up with the equipment. A trail harvester could be purchased for $1,000 to $3,200, depending upon the make, and would perform equally well if certain field practices could be modified.

CONCLUSIONS

A No. 2 McCormick-Deering or a Fox field forage harvester, or presumably any similar make of machine, can be modified to perform a creditable job of harvesting and chopping Napier grass for green forage. Speeds of 1 to 1½ miles per hour should be used to reduce damage to machinery and limit grass intake within the capacity of the machine. Field efficiencies under present agronomic practices will not be much over 40 to 50 percent. The harvester chopper can be operated by one man. Rough fields cause frequent breakage of machinery parts and consequent work stoppages.

Crawler tractors should be used in deep furrows and ditches unless mule cleats are used on wheel equipment. Cutting is better regulated by moving the harvester across the rows rather than along the planted row. Horsepower requirements for auxiliary power depend upon field speed and yield in tons per acre. Twenty horsepower is required for the No. 2 McCormick-Deering harvester under full-cut conditions at 1 mile per hour in yields of 15 to 25 tons per acre.

SUPPLEMENTAL HARVESTING INFORMATION

HARVESTING KOA HAOLE

Both the McCormick-Deering and Fox harvesters, using the corn unit, operated well in stands of koa haole. The Fox machine was operated in fields on the Puunene Dairy, Maui. It should be noted that pneumatic tires are very susceptible to puncture or bruising from the sharp koa stumps. The McCormick-Deering machine was operated in stands of old koa at Waialae Ranch on May 14, 1948. The machine was able to handle 6-foot stands and stem diameters up to ½ inch. Larger stem diameters stopped the sickle.

HARVESTING PANICUM GRASS

To extend information on mechanical field equipment for harvesting dairy forage, further trials with the Fox harvester chopper were made, using the mower bar unit in place of the corn attachment. This 5-foot mower bar unit is interchangeable with the Napier harvesting unit. The mowing attachment is provided with a reel located above the sickle bar to climb over the crop and help bring the grass onto the feed table of the machine.

During the first trial, when opening the field, the sickle drive shaft and reel drive gears were immediately wrapped and fouled with panicum. Moving the cut grass from the sickle bar across the feed table to the chopping unit was also difficult.

To rectify these difficulties protective guards were fabricated around the shafts and drive gears. The machine had provisions for two additional feed table chains with spur links, and it was felt that their installation would facilitate moving the cut grass across the feed table. The necessary spur links were fabricated and the chain was assembled and installed.

FIGURE 13. Fox harvester with sickle bar attachment operating in Panicum grass. Fred Ruis Dairy, Kaneohe.

Trials were conducted at Freddy Ruis' Dairy, Oahu, on August 5 and 6. (See figure 13.) The machine operated very satisfactorily, but the field speeds had to be kept close to 1 mile per hour because of the density of the crop. On August 5 approximately 3 tons of grass were harvested, which met the needs of the dairy. On August 6 operating field data were obtained. The chopped feed was blown directly from the harvester into a four-wheel pull-behind trailer. Field data are as follows:

Net weight grass harvested	2,040 pounds
Time of harvesting	7 minutes 13 seconds
Total time harvesting including return time	9 minutes 13 seconds
Field speed	1.16 miles per hour
Rate of harvesting	281 pounds per minute

On August 6 an additional 1½ tons were harvested and delivered into a truck driven alongside the harvester. The density of the chopped grass in the trailer was approximately 20 pounds per cubic foot.

HARVESTING NAPIER GRASS WITH FOX MOWER ATTACHMENT

The Fox harvester was used to demonstrate the mower unit in Napier grass. Trials on Kauai gave negative results in tall growth and heavy stands, but operations on Maui in young Napier, from 4 feet to 4½ feet high, were successful. In tall grass the length of the stalk, combined with the short apron on the lower head, prevented proper movement of the stalks to the cutting unit. Some of the cut material lay in a tangled mass on the apron and some material was caught and pushed along in front of the mower bar unit, which prevented further mowing of the standing grass. In short grass the stalks fell over onto the feeding apron and were moved without difficulty into the chopping unit.

HAWAII SELF-PROPELLED FORAGE HARVESTER

After a review of trail-type equipment the dairy industry presented their main objections, which were as follows:

Trail equipment means a tractor, harvester, and wagon, hitched one behind the other. Dairymen felt that the fields were too rough and small for such equipment to operate efficiently. They preferred a self-propelled forage harvester which would embody the harvester unit, storage bin, and propulsion unit in a single machine. The cash outlay for such equipment is high when compared with trail-type harvesters.

A machine of this type was assembled, using as basic units a 40-drawbar horsepower International T-9 wide-tread crawler tractor, the modified No. 2 McCormick-Deering field forage chopper, and a 20-horsepower VE-4 Wisconsin engine for an auxiliary power unit. A 25-horsepower VF-4 is recommended. (See figure 24.) A steel bin 3½ by 6 by 7 feet was fabricated and mounted overhead on two pin pivots. The bin support is steel framework bolted to each side of the right track frame. The bottom of the bin is 8 feet 5 inches from the ground level. The bin dumps to the right by rotating on these pin hinges and the chopped grass passes through a swinging end-gate hinged at the top of the bin frame. The power machinery for dumping was mounted directly below the bin and consists of a rear power-take-off and clutch assembly, a reversible gear box, and a winch drum and brake assembly. A wire cable, connecting the drum to the bin, makes a few turns around the winch drum and secures to two points an equal distance apart and on opposite sides of the bin pivot points on the bin floor frame. To tilt the bin the winch drum takes up on one side of the cable and lets out an equal amount of cable on the other side of the drum. A compression coil spring shock device was installed between the cable and bin to place an initial tension of about 1,000 pounds on the wire cable to hold the bin against its seat when not in the tilting position. The spring shock device also acts as a safety in case the operator places too heavy a strain on the cable when reseating after dumping.

The harvester unit was mounted on a cantilever beam supported by framing bolted to the left track. Pin hinges connect the harvester unit to the beam. This method of mounting permits the harvester unit to rotate in one plane and is controlled by a mechanical raise-and-lower lever within easy reach of the driver. The lever raises or lowers the harvester to adjust the height of cut and for transport in and out of the fields. The main reason for restricting motion to one plane was to simplify the machine and lower construction costs. The disadvantage of this method of mounting is that it fixes the motion of the harvester unit to the motion of the tractor. In maneuvering in a field with deep ridges and lines certain positions of the tractor will cause the cantilever mounting beam to dig into the ground. It was felt that the harvester unit could function properly on one fixed pivot axis if the fields could be reworked and made reasonably free from deep ditches and furrows. The auxiliary engine to provide power for the harvester is mounted directly behind the tractor.

The present location of the bin was selected to give the driver an unobstructed view, to place the bin high enough to dump directly into

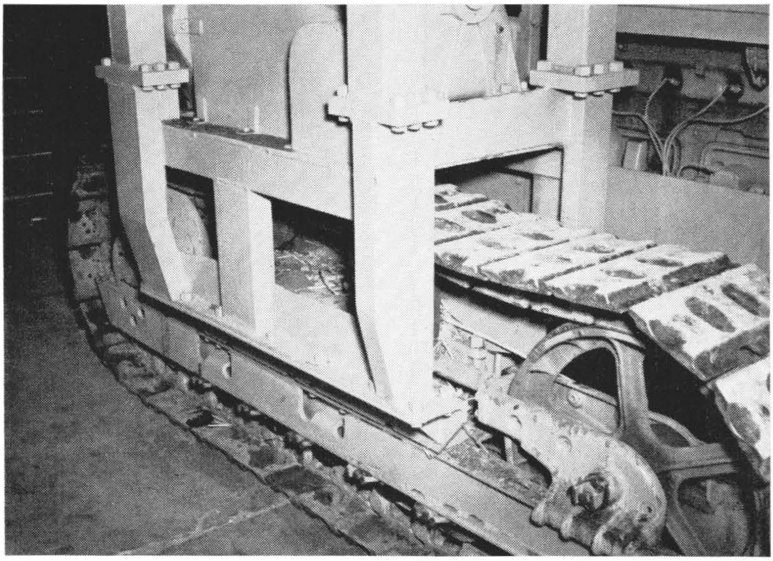


FIGURE 14. Bin support framing. This frame is bolted to only the right tractor track.

FIGURE 15. Bin cable tension device. The bin dumping winch pulls down on this device which compresses the coil spring inside the cylinder. This in turn pulls the bin into its seat. Further compression of the spring maintains a constant pull and holds the bin fixed in place except while dumping.

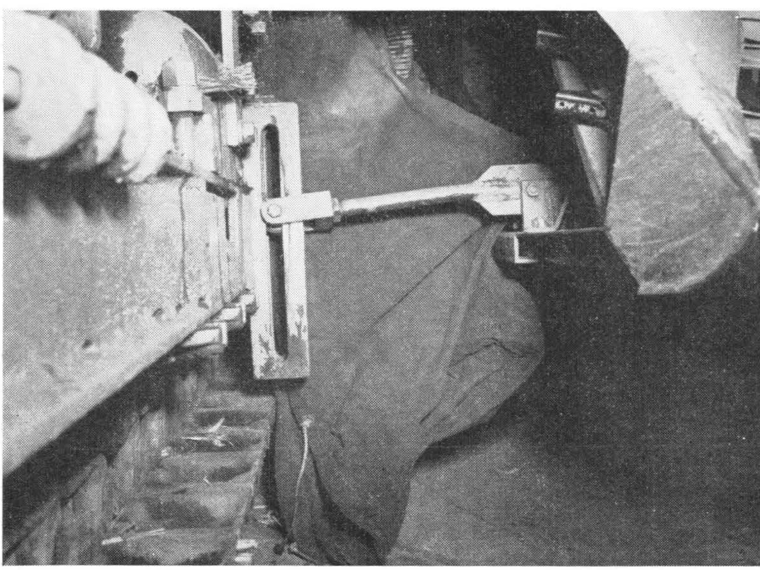


FIGURE 16. Snubber from nose of harvester to tractor. This prevents the harvester from twisting its supports if the sliding shoes become lodged while operating in the field.

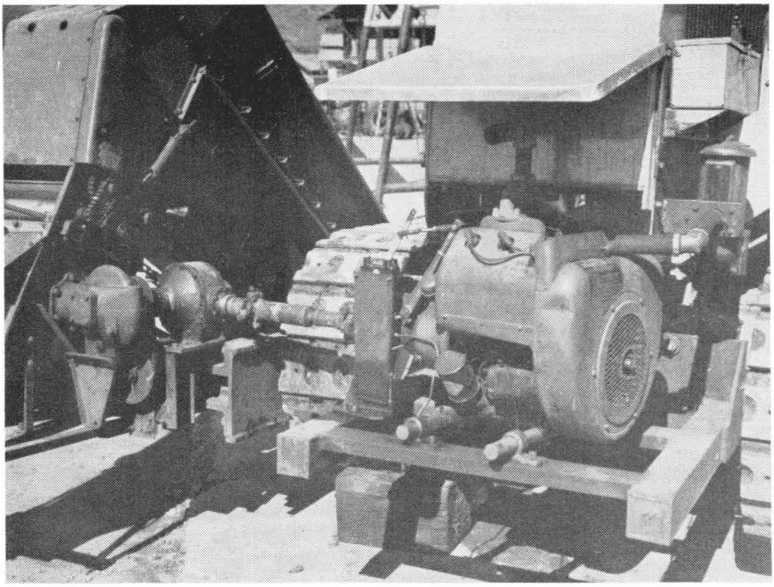


FIGURE 17. Auxiliary engine, mount, torque tube, and differential drive system mounted on the after end of the tractor.

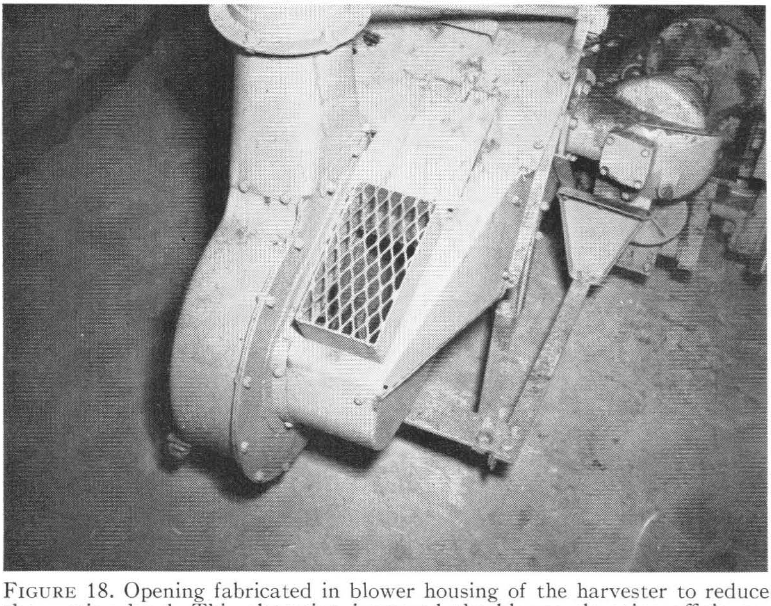


FIGURE 18. Opening fabricated in blower housing of the harvester to reduce the suction head. This alteration increased the blower elevating efficiency.

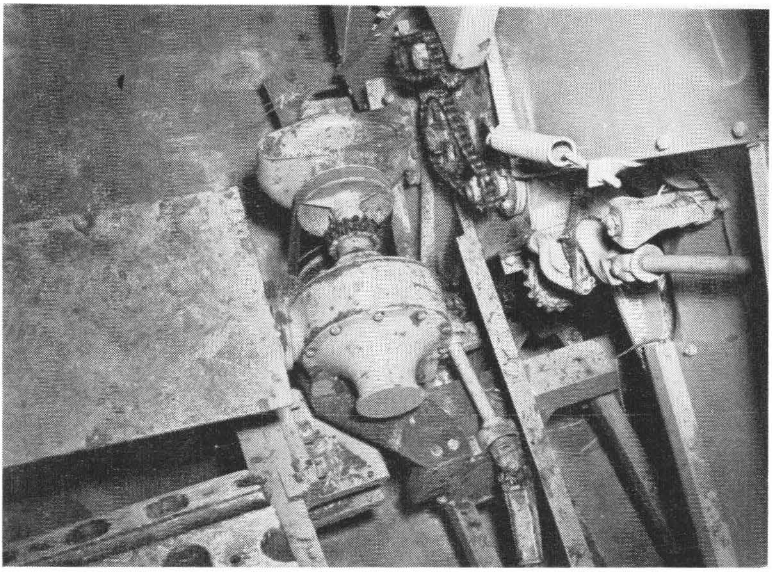


FIGURE 19. Differential drive between auxiliary engine and harvester input gear box. Figure 17 presents another view of this drive.

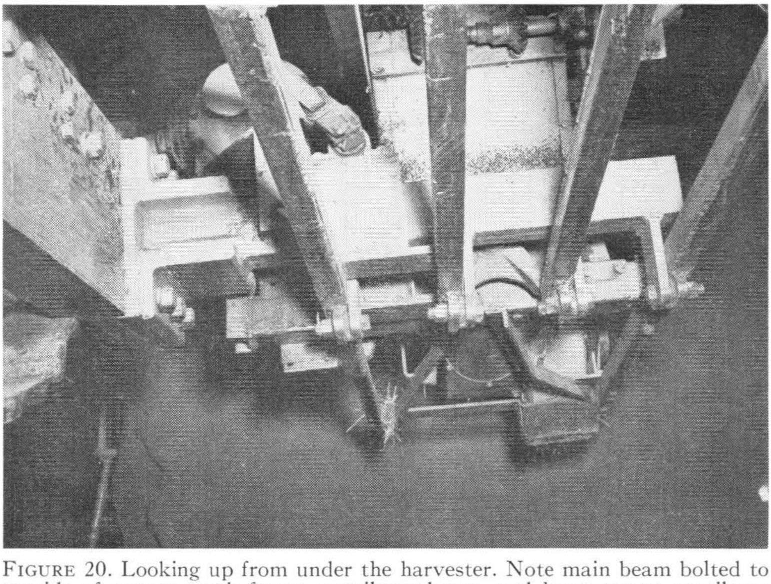


FIGURE 20. Looking up from under the harvester. Note main beam bolted to outside of tractor track frame, cantilever beam, and harvester to cantilever beam hinge system.

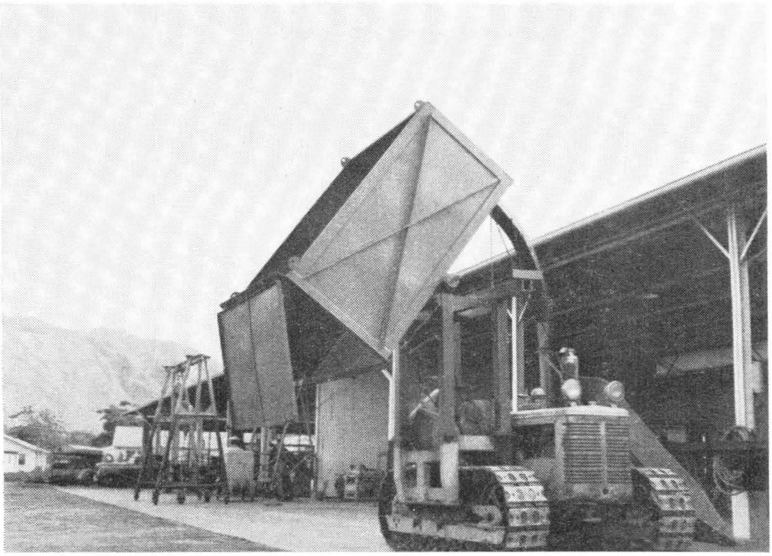


FIGURE 21. Bin in dumping position.

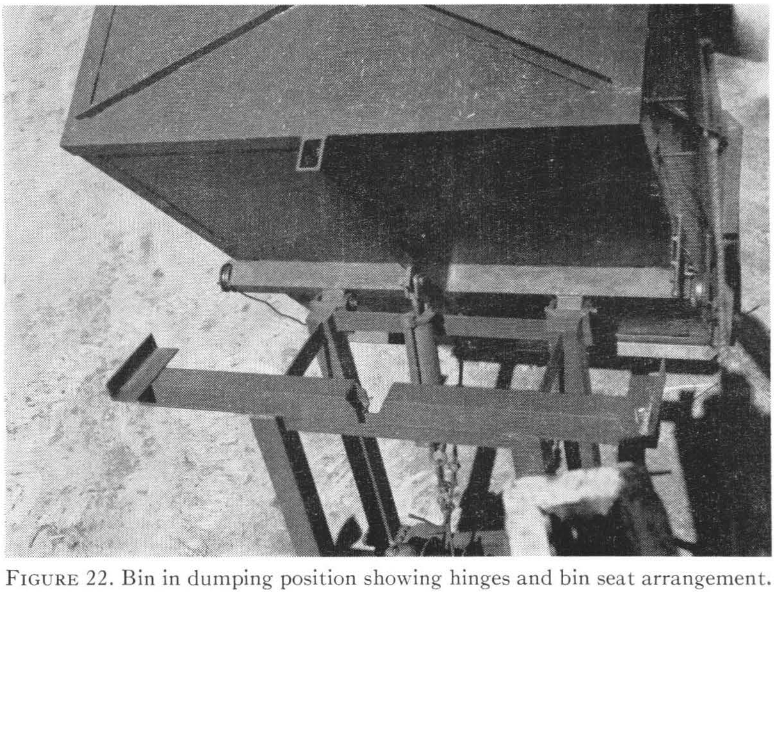


FIGURE 22. Bin in dumping position showing hinges and bin seat arrangement.

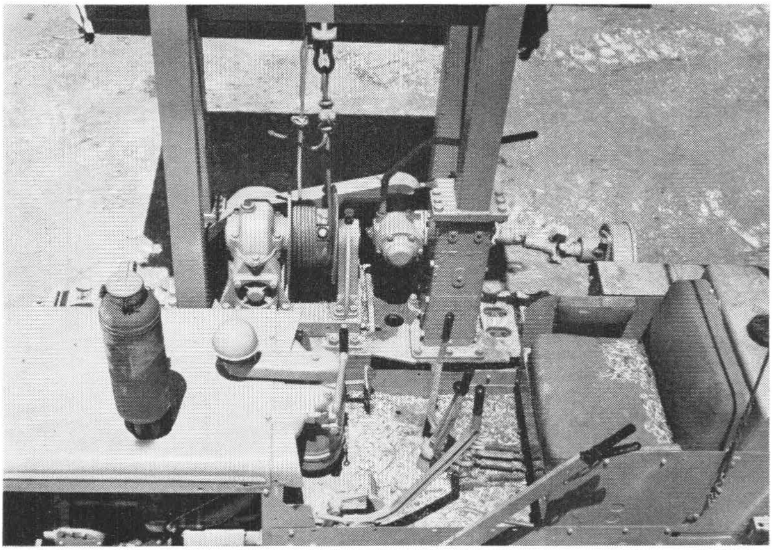


FIGURE 23. Bin winch drum and cable connections.

FIGURE 24. Hawaii self-propelled forage harvester under field tests.

TABLE 6. Field operating data—Hawaii self-propelled forage harvester.

DATE	LOCATION OF TRIAL	ACRES HARVESTED	LAND CONDITION	RATE OF HARVESTING*		TIME IN FIELD MINUTES	YIELD IN TONS PER ACRE
				Pounds per minute	Tons per hour		
1/12/49	University of Hawaii	0.137	Raining and rough	111	3.3	37.75	15.3
1/13/49	University of Hawaii	.067	Dry with dew, rough	90.5	2.72	36.5	24.2
1/14/49	University of Hawaii	.101	Dry with dew, rough	86.5	2.6	43.5	18.5
1/15/49	University of Hawaii	.084	Dry with dew, rough	95.0	2.85	38.85	21.9
1/26/49	Waialae Ranch	.....	Dry	105	3.16	101.0	....
1/27/49	Waialae Ranch	.....	Dry	127	3.82	105.0	....
1/29/49	University of Hawaii	.....	Dry and smooth	114	3.40	34.3	....
2/1/49	University of Hawaii	.....	Dry and smooth	119	3.58	27.7	....
2/2/49	University of Hawaii	.....	Dry and smooth	115	3.45	26.75	....
2/3/49	University of Hawaii	.....	Dry and smooth	125	3.75	39.94	....
2/4/49	University of Hawaii	.....	Dry and smooth	124	3.72	44.63	....
					Ave. 3.58		
3/22/49	University of Hawaii	.....	Dry and rough	101 †	3.03	26	....
3/23/49	University of Hawaii	.....	Dry and rough	86.5†	2.60	43	....
3/24/49	University of Hawaii	.....	Dry and rough	80.0	2.40	53	....
3/25/49	University of Hawaii	.....	Dry and rough	83.0	2.49	52	....
3/26/49	University of Hawaii	.....	Dry and rough	94.0	2.82	54	....
					Ave. 2.67		

* Includes total field time.
† Cutting time only.

a truck or trailer, and finally to mount the bin on single pin hinges.

Another method of dumping should be mentioned. A tractor-engine-driven hydraulic pump combined with double-acting hydraulic cylinders can replace the present power-take-off and winch drum assembly for bin dumping and bin door closing. The use of hydraulic equipment is justified as it would simplify construction and save weight. The present dumping system was used since parts were in storage in the shop.

To reduce the possibility of springing the harvester unit mounting hinges, a snubber attachment was fabricated and attached to the forward end of the harvester unit. This prevents the rotation of the harvester unit about a vertical axis if the gatherer shoes dig into the soil and plant stools while turning. The harvester unit also floats to take care of the difference in terrain and relative movements of the tractor and harvester units, and this spring floating mechanism is combined in the raise-and-lower mechanism. Some difficulty was encountered by the inadequate capacity of the blower at high rates of chopping. This was rectified by cutting a 6- by 10-inch-square hole in the rear sheet cover of the blower. This reduced the suction head on the blower and increased its capacity. No further trouble has been encountered in elevating the chopped feed to the bin.

This self-propelled forage harvester operates well under all types of weather. No detrimental effects from the flat tractor tracks on the growth of subsequent crops have been noticed to date. The machine can be made to cut square corners under continuous one-way operation. Although it operates both across and along the lines, a more even feeding is obtained by cutting across the lines.

Extensive field harvesting has shown over-all harvesting rates of 3.6 tons per hour under smooth field conditions and 2.7 tons per hour under rough field conditions. (See table 6.)

ECONOMICS

The following section presents data compiled and computed, using equipment and harvesting schedules associated with the Hawaii self-propelled forage harvester. Table 7 presents the equipment inventory and

TABLE 7. Hawaii self-propelled forage harvester—equipment inventory.

	COST HONOLULU	LIFE
Track tractor, 16-inch shoes, 34-drawbar horsepower plus storage bin, dumping mechanism, etc.	$10,000	9,000 hours
Field forage harvester, 62-square-inch throat capacity	925	6,000 tons
Auxiliary air-cooled engine, 20 horsepower	575	6,000 tons
	$11,500	

life of the harvesting and chopping equipment. Table 8 gives the overhead and operating costs per ton. The various measures used are as follows:

I. *Overhead Costs*

A. *Depreciation*

It is assumed that the tractor cannot be used except in the harvesting operations. The life is set at 9,000 hours at 3.6 tons per hour or 32,400 tons. For dairies of 2,400 tons per year and less, a 15-year life is assumed.

The life of the chopper unit and auxiliary engine is set at 6,000 tons. It is assumed that the chopper and engine will last 10 years for the 600-ton-per-year dairy.

B. *Interest*

Interest is based on an average value at 5 percent per year.

II. *Operating Costs*

A. *Fuel and Oil*

Tractor—It is assumed that the tractor averages 10-horsepower output during the harvesting operations. With fuel at 23 cents per gallon and a fuel consumption of 1.2 pounds per horsepower per hour the cost is 44.5 cents per hour. Oil is figured at 3 cents per hour. Fuel and oil charges are 13.2 cents per ton.

Auxiliary engine—Assume 18½-horsepower output during the harvesting operations. Assumed fuel consumption is 0.7 pound of fuel per brake horsepower per hour. Fuel charges are 49.6 cents per hour. Oil is figured at 3 cents per hour. Fuel and oil charges are 14.8 cents per ton.

B. *Repairs*

Tractor repairs are taken at 30 cents per hour. Chopper and auxiliary engine repairs are based on 1.7 cents per ton for the engine and 6.5 cents per ton for the chopper.

C. *Labor*

Labor is figured at 80 cents per hour or 22.2 cents per ton with a 3.6-ton-per-hour over-all rate of harvesting.

Table 8 gives the total operating cost in dollars per ton. The costs vary from $1.27 for the 6,000-ton dairy to $2.50 for the 600-ton dairy.

In considering the acquisition of additional equipment, it is sometimes helpful to compare costs other than depreciation, and so estimate the period in which savings due to use of the new equipment will repay its cost. Table 9 presents figures on the retirement of the Hawaii self-propelled forage harvester through reduced operating costs. The first line shows the annual operating costs for harvest by present methods, assuming that the equipment is already owned and has negligible salvage value, so that there are no charges for interest or depreciation. The second line shows comparable operating costs for a Hawaii self-propelled forage harvester, including a charge for interest. The third line shows the annual savings resulting from the purchase of the Hawaii self-propelled forage harvester under these conditions, and the last items the years required to pay for itself.

The purchase of a Hawaii self-propelled forage harvester appears to be well justified on any diary cutting 2,400 tons or more of feed a year, as the machine should pay for itself in 2 years. A Hawaii self-propelled forage harvester cutting 1,200 tons a year should pay for itself in about

TABLE 8. Hawaii self-propelled forage harvester—overhead and operating costs, dollars per ton.

Tons per Year	6,000	4,800	3,600	2,400	1,200	600
Overhead costs						
Depreciation						
Tractor, storage bin, dumping mechanism, etc.	0.31	0.31	0.31	0.28	0.56	1.11
Chopper and engine	.25	.25	.25	.25	.25	.25
Interest	.05	.06	.08	.12	.24	.48
Operating costs						
Fuel and oil	.28	.28	.28	.28	.28	.28
Repairs	.16	.16	.16	.16	.16	.16
Labor	.22	.22	.22	.22	.22	.22
Total	1.27	1.28	1.30	1.31	1.71	2.50

TABLE 9. Retirement of cost of Hawaii self-propelled forage harvester.

Tons per Year	6,000	4,800	3,600	2,400	1,200	600
Annual operating costs for harvest by present methods	$19,140	$15,312	$11,484	$7,565	$3,828	$1,914
Annual operating costs plus interest for Hawaii harvester	4,260	3,456	2,664	1,872	1,080	684
Difference applicable to retirement of Hawaii harvester	14,880	11,856	8,820	5,784	2,748	1,230
Years to retire new cost of Hawaii harvester	0.8	1.0	1.3	2.0	4.2	9.4

4 years. If 600 tons a year or less is being cut, the harvester should pay for itself in 9 years or more. Under such conditions the harvester might pay for itself before it was worn out or became obsolete, but the purchase of such a costly machine for a small dairy might be risky.

CONCLUSIONS

A self-propelled forage harvester combining the features of self-propulsion, cutting, chopping, and intermittent storing can be assembled at a minimum cost of $11,500. The purchase of such a machine is justified for dairies cutting 2,400 tons or more feed per year. Rates of harvesting vary from 2.6 tons per hour in rough fields to 3.6 tons per hour in smooth fields. Field speeds vary between 0.8 and 1.0 mile per hour. With a 20-horsepower auxiliary power unit this machine cannot cut over 8 tons per hour and still have sufficient reserve power.

COST COMPARISON OF HARVESTING METHODS

Economic studies showing harvesting cost data may vary considerably between dairies with identical harvesting machinery. These harvesting cost tables are of prime value when comparing anticipated costs of different harvesting methods on the same dairy.

TABLE 10. Cost comparison of various harvesting methods, dollars per ton.

TONS PER YEAR	PRESENT METHODS	TRAIL-TYPE HARVESTING	HAWAII SELF-PROPELLED FORAGE HARVESTER
6,000	3.39	1.06	1.27
4,800	3.40	1.06	1.28
3,600	3.41	1.07	1.30
2,400	3.45	1.09	1.31
1,200	3.63	1.20	1.71
600	4.09	1.41	2.50

Table 10 gives a summary of the harvesting cost per ton of chopped grass for three harvesting methods and the dairies of various sizes within each method. Present harvesting methods, as described in tables 1 and 2, show the highest cost per ton and the trail-type harvester shows the lowest cost per ton.

Comparison of overhead charges shows that the present harvesting methods give the lowest cost per ton, trail-type equipment next, and the self-propelled harvester the highest. Fuel, oil, and repair charges per ton are nearly the same for the three methods. The main saving derived from mechanization is in labor charges, which are $2.80 per ton for the present

TABLE 11. Harvesting and chopping machinery investment per cow.

SIZE DAIRY IN COWS	PRESENT METHODS		TRAIL HARVESTER CHOPPER		HAWAII SELF-PROPELLED FORAGE HARVESTER	
	Total investment	Investment per cow	Total investment	Investment per cow	Total investment	Investment per cow
500	5,115	10.2	4,575	9.2	11,500	23.0
400	5,115	12.8	4,575	11.4	11,500	28.8
300	5,115	17.0	4,575	15.2	11,500	38.4
200	5,115	25.6	4,575	22.9	11,500	57.5
100	5,115	51.2	4,575	45.8	11,500	115.0
50	5,115	102.3	4,575	91.5	11,500	230.0

methods and $0.22 per ton for the trail and self-propelled machines. However, factors other than costs enter into the over-all picture, and in many cases mechanization is not recommended.

Table 11 shows, on a per-cow basis, the initial investment in harvesting equipment for the three methods of harvesting. Note that the investment per cow for the present methods and trail-type harvester are nearly the same.

HARVESTING METHODS AND FIELD CONDITIONS

Field experience has shown that land conditions have an important bearing in the selection of harvesting machinery. Field size and shape, including natural and artificial boundaries, have a direct bearing on the most efficient and economical method of harvesting. Trail harvesting machinery can be adapted to large, regularly shaped areas where turning is held to a minimum. Cutting square corners around small fields involves considerable maneuvering with a trail machine but is easy with the self-propelled unit. A field is normally opened by hand to provide a path wide enough to let the harvester make the first cut without running down the crop. Running over the first swath is not recommended because the harvester will not pick up this flattened material successfully. If desired,

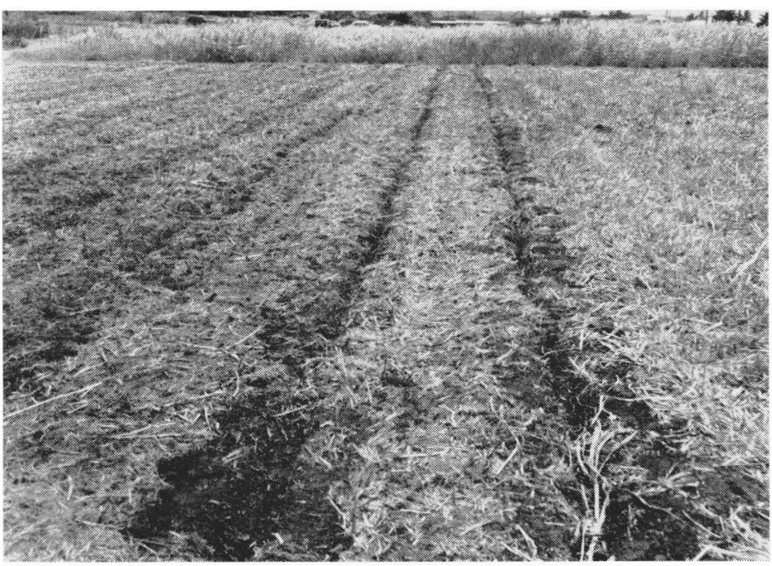


FIGURE 25. Napier field leveling consisting of disking, floating, furrowing, and rolling provides a quick way of renovating rough fields without taking a field out of production. Tests are now underway to determine what effect renovating has on subsequent yields. Leveling of fields reduces machinery strain, increases field speeds, and improves harvesting.

the grass may be run down and later harvested by tractor mower rather than by hand. Headlands are usually not provided except for roadways, since fallow land becomes a weed problem.

Land surface characteristics are a deciding factor in mechanization. The use of either harvester in rough fields and over deep irrigation lines is not recommended, because the continued shock loads will tire the driver and eventually render the equipment useless. The self-propelled machine is not recommended for land slopes beyond 30 degrees or 57 percent, but the trail harvester can be operated on any grade considered safe for maneuvering without overturning.

Harvesting in the rain presents no particular problem for the self-propelled harvester, but trail equipment, especially with wheel tractors, becomes almost impossible on wet ground. Track equipment has an advantage over wheel equipment because of lower soil-bearing pressures and therefore does not tend to sink in loose ground or damage soil by compaction.

CONCLUSIONS

Mechanical harvesting is a decided laborsaving. Where field conditions are satisfactory, trail equipment can operate at a lower cost and a lower initial investment than a self-propelled unit. Fields which are not satisfactory for the trail harvester can be easily handled by the self-propelled machine. If neither harvester can be operated efficiently or if the land acreage in crop is too small to warrant such an investment, it may be best to follow the present harvesting methods.

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